Effect of Shift in Polarization Orientation Angle on Multi-wavelength Fully Polarimetric Data

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Abstract — Polarization orientation angle is the angle between the semi major axis of the polarized wave and the horizontal axis along the line of sight. Polarization orientation angle (OA) shift in backscatter SAR signal induces error in decomposition modelling leading to misinterpretation of results. Studies have been carried out to study the effects of the shift on coherence matrix and on the decomposition products obtained. In this study, the potential of polarization OA shift on decomposition modelling of multi-wavelength fully polarimetric data for scattering information retrieval was investigated. Fully Polarimetric data in L-, C- and X-band of ALOS PALSAR, RADARSAT-2 and TERRASAR-X, respectively were used for the study. The study area is Manali, Himachal Pradesh. This study is aimed at a comparative analyses of surface, double bounce and volume scattering products obtained before and after compensation for polarization OA shift in fully polarimetric data. Coherency matrix was extracted from the data sets and shift in polarization OA was calculated. The Circular Polarization based technique for estimation of OA shift is utilized in this study. It was observed in the present study that the estimated OA shift obtained for various frequencies shows decrease in peakness and an increase in deviation from mean, with increasing frequency. The results obtained from ALOS PALSAR data showed a decreasing trend for volume power and an increasing trend for double bounce power after polarization OA compensation. For the C band RADARSAT-2 data, the trend was sharper in case of change in double bounce power than for change in volume scattering power after polarization OA compensation. The double bounce power showed an overall increase, with sharp changes in vegetated and water regions as compared to the urban regions. The volume scattering power for RADARSAT-2 showed a small increase in case of urban and water regions, and a sharp decrease for vegetated areas. The results obtained for TERRASAR-X showed no change in trend for both volume and double bounce scattering power after OA compensation. Overall, the volume scattering power decreases for vegetated areas, with higher decrease in C-band data, but the study did not show a definitive trend in other regions. The double bounce scattering power showed an increasing overall trend after OA compensation, with the increase higher in case of C Band data as compared to L Band data. The double bounce scattering power change was observed to be higher in vegetated and water areas as compared to urban regions. As helix scattering is roll invariant, it should not change due to OA shift. However an interesting result is obtained which shows a change in the helix scattering power after OA compensation contrary to theory. This study concluded that, with decreasing frequency, there is an increase in the effect of OA shift in polarimetric decomposition modelling for scattering information retrieval. Overestimation of volume scattering and underestimation of double-bounce scattering power were recorded in polarimetric decomposition modelling due to the shift in polarisation OA. Polarisation OA compensation showed increase in double-bounce scattering and decrease in volume scattering in C-band and L-band fully polarimetric data, whereas no change was observed for X-band data. The study strongly recommends OA compensation of fully polarimetric C-band and L-band data for reliable scattering information retrieval using decomposition modeling.

Keywords — SAR, Polarization Orientation Angle, Multi-wavelength, decomposition, Fully Polarimetric SAR (Pol-SAR)

I. INTRODUCTION

Polarimetry is an important technique used for target characteristics determination in Synthetic Aperture Radar (SAR) data analysis. The backscattered signal is collected by the sensor and the relation between incident \(E_I\) and scattered \(S\) signal is given by the scattering matrix \([S]\)

\[ E_S = [S]E_I \]

The information contained within the backscattered signal obtained in all polarizations (quad-pol) is separated into basic scattering mechanisms through the use of Polarimetric target decomposition techniques[1],[2]. Various target decomposition techniques are reviewed by Cloude and Pottier in [3]. Yamaguchi Four Component model based decomposition technique [4] is considered for this paper. Overestimation of volume scattering power and negative power on some pixels in double bounce scattering power are the problems associated with model based decomposition [1]. Orientation angle compensation negates these problems [1]. Polarization Orientation Angle is defined as the angle between the maximum amplitude of the polarized wave and the horizontal axis symbolized by Greek letter \(\psi\) [5], as

\[ \psi = \tan^{-1}\left(\frac{|E_{x1}|}{|E_{y1}|}\right) \] (1)

After interaction with target, the Orientation Angle (OA) of the wave is shifted from zero. The polarization OA are induced by nonzero azimuth slope surfaces and man-made targets not aligned in along track direction [1]. The induced OA \(\psi\) is calculated in terms of azimuth and range slopes as given by the following equation [6]
\[ \tan \psi = \frac{\tan \omega}{-\tan \cos \phi + \sin \phi} \quad (2) \]

A. OA compensation technique

Circular Polarization technique proposed by Lee et al. [6],[7] is used in this paper. The effectiveness of this method has been demonstrated and verified by comparison with Interferometric SAR measurements [1]. The algorithm as reviewed in [1] is presented in this section.

For a scattering medium rotated by an angle \( \psi \), the orientation angle can be expressed [1] as:
\[
\tan(-4\psi) = \frac{-4\Re((S_{HH} - S_{VV})S_{HV}^*)}{4(|S_{HH}|^2 + |S_{VV}|^2)}
\]

The OA is phase wrapped. To extract useful information out of this OA, it has to be unwrapped by adding \( \pi [1] \) as in:
\[
\eta = \frac{1}{4} \left[ \tan^{-1} \left( \frac{-4\Re((S_{HH} - S_{VV})S_{HV}^*)}{(|S_{HH}|^2 + |S_{VV}|^2)} \right) + \pi \right]
\]

Where
\[
\psi = \begin{cases} \eta, & \text{if } \eta \leq \pi/4 \\ \eta - \frac{\pi}{2}, & \text{if } \eta > \pi/4 \end{cases}
\]

(4)

C. Yamaguchi Four Component Decomposition

Yamaguchi et al. [8] decomposed the coherence matrix \([T]\) into four scattering mechanisms. The following equation (5) gives the representation of decomposed coherence matrix. In (5), \( \alpha, \beta \) are complex observables defined in [8] and the terms \( f_\alpha, f_\beta, f_\alpha^*, f_\beta^* \) are the powers of the surface, double, volume and helix scattering respectively:
\[
[T] = \frac{f_\alpha}{1+|\beta|^2} \begin{bmatrix} 1 & \beta^* & 0 & 0 \\ 0 & |\beta|^2 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} + \frac{f_\beta}{1+|\alpha|^2} \begin{bmatrix} |\alpha|^2 & 0 & \alpha & 0 \\ 0 & 1 & \alpha^* & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}
\]

(5)

III. DATA SETS AND STUDY AREA

In this study, fully polarimetric data in L-, C- and X- band was utilized. ALOS PLASAR data in L-band, RADARSAT-2 data in C-band and TERRASAR-X data in X-band was used. Table I gives a brief description of the data sets.

<table>
<thead>
<tr>
<th>TABLE I DESCRIPTION OF DATA SETS</th>
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</thead>
<tbody>
<tr>
<td>Data Set</td>
</tr>
<tr>
<td>Polarization</td>
</tr>
<tr>
<td>Wavelength</td>
</tr>
<tr>
<td>Resolution (m)</td>
</tr>
<tr>
<td>Incidence Angle</td>
</tr>
<tr>
<td>Date of Acquisition</td>
</tr>
</tbody>
</table>

The study area selected is Manali, Himachal Pradesh. The area has all three major regions of interest – urban, forest or vegetation and water bodies. Fig 1 represents a Google Earth imagery of the area.

III. METHODOLOGY

Fig 2 shows the flow chart of the methodology. Data sets in all frequencies were processed to generate Scattering matrices. Coherency matrices were generated and Yamaguchi four component decomposition carried out.

Shift in OA is calculated and a new coherency matrix rotated by an angle \( \psi \) is calculated. Yamaguchi Four component decomposition was carried out on the generated matrix. Comparative analysis on the Yamaguchi decomposed products before and after OA shift compensation is carried out.

A patch containing all three areas of interest, namely urban, vegetated and water, were selected and 50 random pixels were chosen from each. Analysis was carried out on these sample points. The following section discusses the results in brief.

![Flow chart of Methodology](image-url)
IV. RESULTS

A. Orientation Angle Shift.

The shift in OA for all three frequency images was calculated. It was observed in the present study that with increase in frequency, there was a decrease in peaked-ness of the distribution and increase in shift from mean (See Fig 3 and Table II). All OA shifts lie in the range of \([-45^\circ, 45^\circ]\).

Following table (Table II) provides the mean and standard deviation of the OA shift in the three data sets:

<table>
<thead>
<tr>
<th>Sr No</th>
<th>Data Set</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ALOS PALSAR</td>
<td>0.1483</td>
<td>21.535</td>
</tr>
<tr>
<td>2</td>
<td>RADARSAT 2</td>
<td>-0.17079</td>
<td>24.007</td>
</tr>
<tr>
<td>3</td>
<td>TERRASAR X</td>
<td>-3.307</td>
<td>27.592</td>
</tr>
</tbody>
</table>

As can be seen from the Fig 3(C), the X-band TERRASAR-X data shows an equi-probable distribution of OA Shift. This signifies that there is no OA Shift in the X-band data set. The histogram of other two data sets, Fig 3(A) and Fig 3(B) show a Gaussian distribution though the kurtosis decreases with increase in frequency.

B. Multi-frequency Scattering Power Comparison

A transect of 50 samples each from Urban, Vegetation and Water areas in each frequency data set was analysed for each scattering mechanism as described in Yamaguchi Four Component Decomposition, i.e. Double, Volume, Surface and Helix Scattering. The graphs show the variation of scattering powers in various regions before and after Orientation Angle Compensation or Deorientation.

Double bounce scattering power as shown in Fig 4(A) and 5(A) shows an overall increase in scattering power after OA Compensation. The increase of equal magnitude was observed for both C- and L-band data. However there was no change observed for X-band data. In the three regions, Deorientation effect was more pronounced in vegetated and water regions as compared to the urban areas.

For Volume scattering, as depicted in Fig 4(B) and 5(B) before and after OA compensation respectively, the power decreases overall in both C- and L-band data, however no change was observed for X-band data set. This shows volume scattering is overestimated in Yamaguchi decomposition without OA compensation. The overestimation is higher in L-band data as compared to C-band data. As expected, the overestimation of volume scattering power is higher in vegetated areas as compared to other regions.

Fig 4(C) shows the odd bounce scattering before deorientation. Odd bounce power did not show any definitive trend of change in scattering power after OA compensation (Fig 5(C)). The X-band data set however showed no change in odd bounce scattering after OA compensation.

The helix scattering power should not change as it is roll invariant [1]. However, interesting results were obtained on analysis. It was observed that the helix scattering power changes after OA compensation. As depicted in Fig 4(D) and Fig 5(D), there is an overall increase in helix scattering power with increase higher in case of L- than C-band data set. X-band data does not show any OA shift effect. Helix scattering power shows higher increase in vegetated areas as compared to other regions.

V. CONCLUSION

In this paper an analysis has been carried out to study the effect of shift in orientation angle on multifrequency fully polarimetric data sets. It has been shown that as the frequency of the data set increases, the effect of OA shift decreases. Orientation angle shift does not show any effect...
on X-band TERRASAR-X data set. This may be attributed to the canopy backscattering most of the incident wave leading to very low volume scattering and hence no shift in polarization orientation angle.

Fig 4. Backscattering powers before Orientation Angle Compensation. The Yamaguchi scattering mechanisms are (A) Double Bounce Scattering, (B) Volume Scattering, (C) Odd Bounce Scattering and (D) Helix Scattering. The samples are divided into three regions of 50 pixels each in Vegetation, Urban and Water regions respectively.
Fig 5. Backscattering powers after Orientation Angle Compensation. The Yamaguchi scattering mechanisms are (A) Double Bounce Scattering, (B) Volume Scattering, (C) Odd Bounce Scattering and (D) Helix Scattering. The samples are divided into three regions of 50 pixels each in Vegetation, Urban and Water regions respectively.

Furthermore it is shown that the volume scattering is overestimated and OA compensation reduces the volume scattering power. The double bounce scattering power shows an increase after OA compensation, thus solving the problem of pixels having negative powers after Yamaguchi decomposition. Analysis to study the effect of OA shift in various land use regions – urban, water and vegetation is also carried out.

Another important point highlighted in this study is the change observed in helix scattering power after OA compensation contrary to the theory. The reasons for this behavior need to be examined in detail.

VI. RECOMMENDATION
Shift in orientation angle has a significant impact on the decomposed outputs. It is recommended to perform OA compensation as a standard SAR data processing step to obtain accurate results. As fully polarimetric SAR decomposition results are used in a variety of applications, it is recommended to perform OA compensation for application such as Bio-physical Characteristics estimation, Urban mapping, Agricultural mapping, Snow/ Ice identification etc. as these studies require accurate prediction of scattering mechanisms involved.

REFERENCES